

# Prompt Photon and Inclusive $\pi^0$ Production at RHIC and LHC

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We present results for prompt photon and inclusive  $\pi^0$  production in p-p and A-A collisions at RHIC and LHC energies. We include the full next-to-leading order radiative corrections and nuclear effects, such as nuclear shadowing and parton energy loss. We find the next-to-leading order corrections to be large and  $p_T$  dependent. We show how measurements of  $\pi^0$  production at RHIC and LHC, at large  $p_T$ , can provide valuable information about the nature of parton energy loss. We calculate the ratio of prompt photons to neutral pions and show that at RHIC energies this ratio increases with  $p_T$  approaching one at  $p_T \sim 10$  GeV, due to the large suppression of  $\pi^0$  production. We show that at the LHC, this ratio has steep  $p_T$  dependence and approaches 10% effect at  $p_T \sim 20$  GeV.

## 1. INTRODUCTION

In high-energy heavy-ion collisions hard scatterings of partons occur in the early stages of the reaction, well before a quark-gluon plasma might have been formed, producing fast partons that propagate through the hot and dense medium and lose their energy. It has been predicted that parton energy loss would result in the suppression of pion production in heavy-ion collisions relative to hadron-hadron collisions [1]. Recent data on inclusive  $\pi^0$  production at RHIC energy of  $\sqrt{s} = 200$  GeV [2] and at large  $p_T$ ,  $3\text{GeV} \leq p_T \leq 8\text{GeV}$ , confirms this prediction, however the observed suppression was found to become stronger with increasing  $p_T$ , providing a new challenge for theoretical models.

In addition to being of special interest for studying parton energy loss effects, large- $p_T$   $\pi^0$  mesons form a significant background for the prompt photons. Theoretical predictions for the prompt photon production [3] and for the ratio of prompt photons to pions at RHIC and LHC energies are crucial for studying possible quark-gluon plasma formation via photons.

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\*talk presented by I. Sarcevic.

## 2. INCLUSIVE $\pi^0$ AND PROMPT PHOTON PRODUCTION AT RHIC AND LHC

In perturbative QCD, the inclusive cross section for pion production in a hadronic collision is given by:

$$E_\pi \frac{d^3\sigma}{d^3p_\pi}(\sqrt{s}, p_\pi) = \int dx_a \int dx_b \int dz \sum_{i,j} F_i(x_a, Q^2) F_j(x_b, Q^2) D_{c/\pi}(z, Q_f^2) E_c \frac{d^3\hat{\sigma}_{ij \rightarrow cX}}{d^3p_c} \quad (1)$$

where  $F_i(x, Q^2)$  is the  $i$ -th parton distribution in a nucleon,  $D_{c/\pi}(z, Q_f^2)$  is the pion fragmentation function and  $d^3\hat{\sigma}_{ij \rightarrow cX}/d^3p_c$  are parton-parton cross sections. Prompt photon production is obtained using similar expression, except that photon production has contributions from direct processes and bremsstrahlung processes, where only bremsstrahlung processes are convoluted with photon fragmentation function,  $D_{c/\gamma}(z, Q_f^2)$ .

We calculate inclusive pion production in proton-proton collisions using MRS99 parton distributions [4], BKK pion fragmentation function [5] and we include leading-order,  $O(\alpha_s^2)$ , and the next-to-leading order,  $O(\alpha_s^3)$ , subprocesses [6]. Our prediction for inclusive  $\pi^0$  production at RHIC energy of  $\sqrt{s} = 200$  GeV, and for  $p_T > 3$  GeV [7], was found to be in excellent agreement with PHENIX data [2], indicating that perturbative QCD approach is justified in this kinematic region.

To calculate the inclusive cross section for pion production in heavy ion collisions, we use Eq. (1) with the parton distributions modified to include nuclear shadowing effect [8] and modified fragmentation function to incorporate parton energy loss [9]. We consider constant parton energy loss [10] as well as energy-dependent energy loss [7]. In Fig. 1 we show our results for the ratio of inclusive cross section for pion production in Au-Au collisions to the one in proton-proton collisions,  $R_{AA}(p_T)$ . We find that for constant energy loss the ratio increases with  $p_T$ , while for the energy-dependent case,  $\epsilon = \kappa E$ , the ratio decreases with  $p_T$ . For  $\kappa = 0.06$  we find excellent agreement with the recent PHENIX data [11]. In Fig. 1 we also show our prediction for  $R_{AA}(p_T)$  in case of prompt photon production. The suppression of prompt photons produced in heavy-ion collisions at RHIC is much less than  $\pi^0$  suppression. This is due to the fact that only bremsstrahlung processes are affected by the parton energy loss, which contribute 24% to the cross section at  $p_T = 3$  GeV and 6% at  $p_T = 12$  GeV. For the same reason, prompt photons are not very sensitive to a different choice of parton energy loss.

In Fig. 2 we show the ratio of prompt photon and  $\pi^0$  cross sections at  $\sqrt{s} = 200$  GeV. We find that for constant energy loss this ratio increases slowly with  $p_T$ , similar to the p-p case, while for  $\epsilon = 0.06E$ , the ratio has strong  $p_T$  dependence, approaching one at  $p_T \sim 10$  GeV. This is due to the strong suppression of  $\pi^0$  production at large  $p_T$ . In Fig. (3), we present  $R_{AA}(p_T)$  for inclusive  $\pi^0$  production and for prompt photon production at the LHC. We find that with constant parton energy loss per collision,  $\epsilon = 1$  GeV, pion suppression decreases from 80% at  $p_T = 5$  GeV to 20% at  $p_T = 40$  GeV, while for  $\epsilon = 0.06E$  the suppression increases from 70% at  $p_T = 5$  GeV to 80% at  $p_T = 40$  GeV. Prompt photon production in Pb-Pb collisions at the LHC is slightly less suppressed than  $\pi^0$  production, for the constant energy loss, while for  $\epsilon = 0.06E$  the suppression decreases slower, from 60% at low  $p_T$  to 30% at  $p_T = 40$  GeV. Nuclear shadowing effects are very small, less than 10%. At this energy we

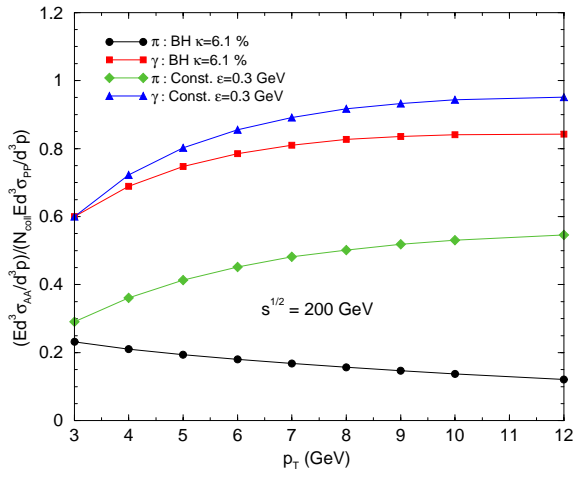


Figure 1. Suppression of  $\pi^0$  and prompt photon production in Au-Au collisions relative to the binary collision scaled proton-proton case, at  $\sqrt{s} = 200$  GeV.

note that suppression of prompt photons is similar to the  $\pi^0$  case, because at LHC energy prompt photon production has 60% contribution from bremsstrahlung processes, which are modified due to the energy loss in a similar way to the  $\pi^0$  case. We find that  $\pi^0$  production is very sensitive to the parton energy loss parameters.

In Fig. 4 we show the ratio of prompt photons and pions at the LHC. We find that for constant energy loss this ratio increases slowly with  $p_T$ , similar to p-p case, while for  $\epsilon = 0.06E$  the ratio increases rapidly approaching 0.2 at  $p_T = 35$  GeV.

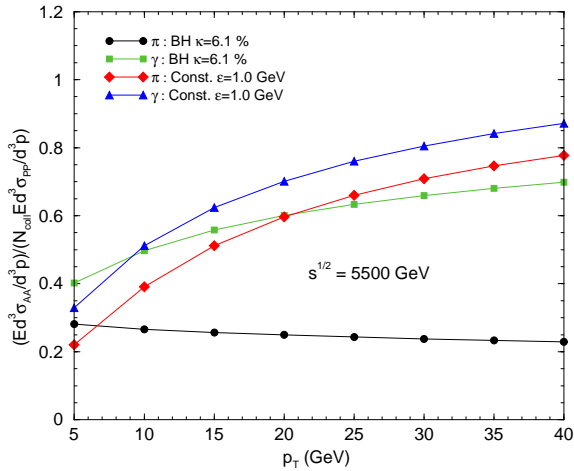


Figure 3. Suppression of  $\pi^0$  and prompt photon production in Au-Au collisions relative to the binary collision scaled proton-proton case, at the LHC.

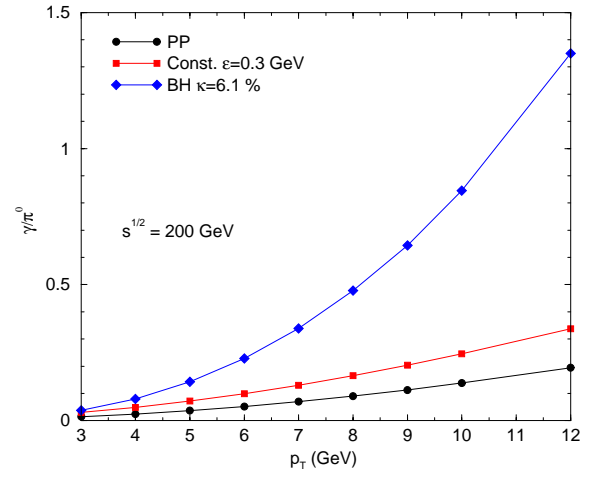


Figure 2. The  $\gamma/\pi^0$  ratio as a function of  $p_T$  at  $\sqrt{s} = 200$  GeV.

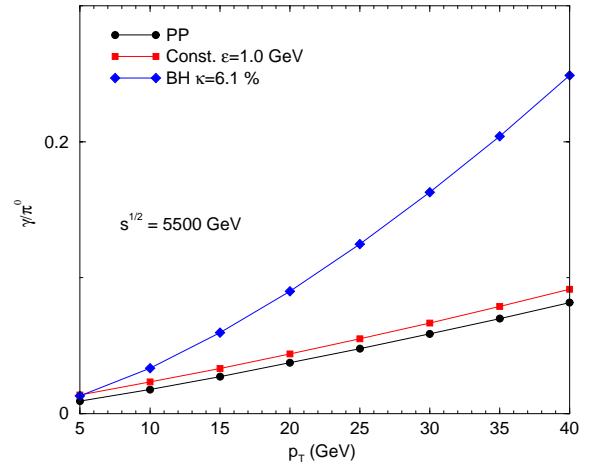


Figure 4. The  $\gamma/\pi^0$  ratio as a function of  $p_T$  at the LHC.

### 3. SUMMARY

We have calculated inclusive pion and prompt photon production cross sections in proton-proton and in heavy-ion collisions at RHIC and LHC energies. We have incorporated next-to-leading order contributions, initial state parton distribution functions in a nucleus and medium induced parton energy loss by modifying the final state pion and photon fragmentation functions.

We find the nuclear K-factor, which signifies higher order corrections, to be large and  $p_T$  dependent and the shape of the  $p_T$  distribution insensitive to the choice of scales [10]. The nuclear shadowing effects are small at RHIC and LHC energies. We show that  $\pi^0$  suppression observed at RHIC can be attributed to the parton energy loss. We also present results for the suppression of prompt photon production at RHIC and LHC, and for the ratio of prompt photon and  $\pi^0$  cross sections, of relevance to separating different sources of photon production.

We are indebted to P. Aurenche and J. P. Guillet for providing us with the fortran routines for calculating  $\pi^0$  and photon production in hadronic collisions and for many useful discussions. We thank D. d’Enterria and M. Tannenbaum for many helpful discussions and suggestions. I.S. is supported in part through U.S. Department of Energy Grants Nos. DE-FG03-93ER40792 and DE-FG02-95ER40906. S.J. is supported in part by the Natural Sciences and Engineering Research Council of Canada. J.J-M. is supported in part by a PDF from BSA and by U.S. Department of Energy under Contract No. DE-AC02-98CH10886.

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